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Analysis of the Deformation Performance of Superimposed Wall Plane

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Abstract. Shear connectors connect the precast interior walls to the cast-in-place exterior walls in a stacked shear wall, and the interface is the weak side of the structure. Based on the converted section characteristic method, the deformation increment control differential equation of composite shear wall was established. the calculation formula of deformation increment under different loads was given, and the influence of load, slip stiffness and temperature on deformation increment was calculated and analyzed. The results show that the parabolic loading form has the greatest effect on the deformation. As the slip stiffness was increased by 6 times, the deformation increment was reduced by about 98%. When the temperature increased from 20° C to 40° C, the deformation increment showed an ascending parabola, but the total deformation increment remained relatively unchanged.

Keywords: Superimposed wall plane; Temperature effects; Converted section method; Differential equations.

1. Introduction

With the swift advancement of economy, science and technology, new materials, new processes and new structures have emerged as the development trend of the modern civil engineering industry. The development of building structures towards high strength, light weight and green is an inevitable demand.Prefabricated buildings can not only enhance industrialization and high construction efficiency but also reduce environmental pollution and energy waste, generating significant economic benefits[1]. As a kind of semi-prefabricated concrete component instead of cast-in-place concrete shear wall, superimposed shear wall has the dual advantages of both cast-in-place concrete wall and precast concrete wall, and has good overall performance.However, there are still some problems in the promotion and use of superimposed shear wall panels [2, 3]：It is difficult to control the bonding degree of the superimposed surface during construction. The joint is the weak link of superimposed shear wall. At present, many domestic and foreign scholars have studied the mechanical properties of superimposed shear walls [4-7], but few have studied the interface properties between prefabricated walls and cast-in-place walls. In this paper, considering the influence of temperature creep effect of concrete, the control differential equation and calculation formula of interface deformation increment of superimposed shear wall are established. At the same the influence of different parameters on the interface interaction of the superimposed shear wall under different load conditions is calculated, which can provide a reference for the practical design of the superimposed shear wall.

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2. Deformation Increment Control Differential Equation

The internal force elements of prefabricated inner wall and cast-in-place outer wall under external load are shown in Fig.1.

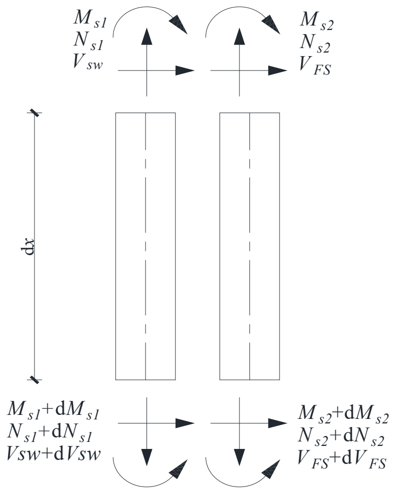

Fig. 1 Microcells in superimposed wall plane

According to internal force balance and converted section characteristic method [8], the governing equation of deformation increment is obtained:

$$\frac{\mathrm{d}^4\Delta W(t)}{\mathrm{d}x^4}-\alpha_3{}^2\frac{\mathrm{d}^2\Delta W(t)}{\mathrm{d}x^2}=\beta_3\frac{\mathrm{d}^2N(t_0)}{\mathrm{d}x^2}+\beta_4\frac{\mathrm{d}^2M(t_0)}{\mathrm{d}x^2}+\beta_5N(t_0)+\beta_6M(t_0)+\beta_7 \tag{1}$$

In the Formula,

$$\alpha_3{}^2=k_L\left[\frac{1}{\overline{E}(t,t_0,T)A(t)}-\frac{y^2(t)}{\overline{E}(t,t_0,T)I(t)}\right];$$

$$\beta_3=-\left[\frac{\overline{E}_{sw}(t,t_0,T)I_{sw}(t)\phi_{sw}(t,t_0,T)y(t_0)+\overline{E}_{FS}(t,t_0,T)I_{FS}(t)\phi_{FS}(t,t_0,T)y(t_0)}{E(t_0)I(t_0)\overline{E}(t,t_0,T)I(t)}+\frac{y_{si}(t)\lambda_1+y_{sj}(t)\lambda_2}{\overline{E}(t,t_0,T)I(t)}\right];$$

$$\beta_4=\left[\frac{\overline{E}_{sw}(t,t_0,T)I_{sw}(t)\phi_{sw}(t,t_0,T)+\overline{E}_{FS}(t,t_0,T)I_{FS}(t)\phi_{FS}(t,t_0,T)}{E(t_0)I(t_0)\overline{E}(t,t_0,T)I(t)}-\frac{y_{si}(t)\gamma_1+y_{sj}(t)\gamma_2}{\overline{E}(t,t_0,T)I(t)}\right];$$

$$\beta_5=-\frac{k_L}{\overline{E}(t,t_0,T)I(t)}\left\{\begin{array}{l}\dfrac{\overline{E}_{sw}(t,t_0,T)I_{sw}(t)\phi_{sw}(t,t_0,T)y(t_0)+\overline{E}_{FS}(t,t_0,T)I_{FS}(t)\phi_{FS}(t,t_0,T)y(t_0)}{E(t_0)I(t_0)\overline{E}(t,t_0,T)A(t)}\\+y(t)\left[\dfrac{\phi_{sw}(t,t_0,T)}{E_{sw}(t_0)A_{sw}(t_0)}+\dfrac{\phi_{FS}(t,t_0,T)}{E_{FS}(t_0)A_{FS}(t_0)}+\dfrac{\lambda_2}{\overline{E}_{FS}(t,t_0,T)A_{FS}(t)}+\dfrac{\lambda_1}{\overline{E}_{sw}(t,t_0,T)A_{sw}(t)}\right]\\+\dfrac{y_{si}(t)\lambda_1+y_{sj}(t)\lambda_2}{\overline{E}(t,t_0,T)A(t)}\end{array}\right\};$$

$$\beta_6=\frac{k_L}{\overline{E}(t,t_0,T)I(t)}\left\{\begin{array}{l}\dfrac{\overline{E}_{sw}(t,t_0,T)I_{sw}(t)\phi_{sw}(t,t_0,T)+\overline{E}_{FS}(t,t_0,T)I_{FS}(t)\phi_{FS}(t,t_0,T)}{E(t_0)I(t_0)\overline{E}(t,t_0,T)A(t)}\\-y(t)\left[\dfrac{\gamma_1}{\overline{E}_{sw}(t,t_0,T)A_{sw}(t)}+\dfrac{\gamma_2}{\overline{E}_{FS}(t,t_0,T)A_{FS}(t)}\right]-\dfrac{y_{si}(t)\gamma_1+y_{sj}(t)\gamma_2}{\overline{E}(t,t_0,T)A(t)}\end{array}\right\};$$

$$\beta_7=k_Ly(t)\left[\frac{G}{\overline{E}_{FS}(t,t_0,T)A_{FS}(t)}\right]。$$

3. Calculation Formula of Deformation Increment

For the superimposed shear wall under different loads, the differential equation of deformation increment control (1-1) has different solutions.

3.1 Bear Horizontal Uniform Load

The incremental deformation solution of prefabricated interior wall and cast-in-place exterior wall of superimposed shear wall under horizontal uniform load is as follows:

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$$
\begin{aligned}
\Delta W(t)=&c_1\mathrm{e}^{\alpha_3 x}+c_2\mathrm{e}^{-\alpha_3 x}-\left(\beta_3+\frac{\beta_5}{\alpha^2}\right)\frac{\beta q\mathrm{e}^{\alpha L/2}}{\left(\alpha^2-\alpha_3{}^2\right)\alpha^4\left(\mathrm{e}^{\alpha L}+1\right)}\left(\mathrm{e}^{\alpha x}+\mathrm{e}^{-\alpha x}\right)-\frac{1}{12\alpha_3{}^2}\left(\frac{\beta_5\beta q}{2\alpha^2}-\frac{\beta_6 q}{2}\right)x^4\\
&-\frac{1}{2\alpha_3{}^2}\left[\frac{\beta_3\beta q}{\alpha^2}-\beta_4 q+\frac{\beta_5\beta q}{\alpha^4}-\frac{\beta_5\beta qL^2}{8\alpha^2}+\frac{\beta_6 qL^2}{8}+\beta_7+\frac{2}{\alpha_3{}^2}\left(\frac{\beta_5\beta q}{2\alpha^2}-\frac{\beta_6 q}{2}\right)\right]x^2+c_3x+c_4
\end{aligned} \tag{2}
$$

3.2 Bear Horizontal Triangular Load

The incremental deformation solution of prefabricated interior wall and cast-in-place exterior wall of superimposed shear wall under horizontal triangular load is as follows:

$$
\begin{aligned}
\Delta W(t)=&\frac{c_1}{\alpha_3{}^2}\mathrm{e}^{\alpha_3 x}+\frac{c_2}{\alpha_3{}^2}\mathrm{e}^{-\alpha_3 x}+c_3x+c_4\\
&+\frac{\left(\alpha^2\beta_3+\beta_5\right)}{\alpha^2}\frac{\left(\frac{q\beta H}{6\alpha^3}-\frac{2q\beta}{H\alpha^5}\right)\mathrm{e}^{-\frac{\alpha H}{2}}-\frac{q\beta}{\alpha^4}}{\left(\alpha^2-\alpha_3{}^2\right)\left(\mathrm{e}^{\frac{\alpha H}{2}}+\mathrm{e}^{-\frac{\alpha H}{2}}\right)}\mathrm{e}^{\alpha x}-\frac{\left(\alpha^2\beta_3+\beta_5\right)}{\alpha^2}\frac{\frac{q\beta}{\alpha^4}+\mathrm{e}^{\frac{\alpha H}{2}}\left(\frac{q\beta H}{6\alpha^3}-\frac{2q\beta}{H\alpha^5}\right)}{\left(\alpha^2-\alpha_3{}^2\right)\left(\mathrm{e}^{\frac{\alpha H}{2}}+\mathrm{e}^{-\frac{\alpha H}{2}}\right)}\mathrm{e}^{-\alpha x}\\
&+\frac{1}{6}\left(\frac{2q\beta_6}{H\alpha_3{}^4}-\frac{2q\beta_5\beta}{H\alpha^2\alpha_3{}^4}-\frac{2q\beta\beta_3}{H\alpha^2\alpha_3{}^2}+\frac{2\beta_4 q}{H\alpha_3{}^2}+\frac{q\beta_5\beta H}{6\alpha^2\alpha_3{}^2}-\frac{2q\beta_5\beta}{H\alpha^4\alpha_3{}^2}-\frac{qH\beta_6}{6\alpha_3{}^2}\right)x^3\\
&+\frac{1}{20}\left(\frac{q\beta_6}{3H\alpha_3{}^2}-\frac{q\beta_5\beta}{3H\alpha^2\alpha_3{}^2}\right)x^5+\frac{1}{2}\left(\frac{qH^2\beta\beta_5}{24\alpha^2\alpha_3{}^2}-\frac{q\beta_6H^2}{24\alpha_3{}^2}-\frac{\beta_7}{\alpha_3{}^2}\right)x^2
\end{aligned} \tag{3}
$$

3.3 Bear Horizontal Parabolic Load

The general solution of incremental deformation between prefabricated interior wall and cast-in-place exterior wall of superimposed shear wall under horizontal parabolic load is as follows:

$$
\begin{aligned}
\Delta W(t)=&\frac{c_1}{\alpha_3{}^2}\mathrm{e}^{\alpha_3 x}+\frac{c_2}{\alpha_3{}^2}\mathrm{e}^{-\alpha_3 x}+c_3x+c_4\\
&-\frac{q\beta\left(\alpha^2\beta_3+\beta_5\right)}{k_L\left(1+\mathrm{e}^{\alpha H}\right)\left(\alpha^2-\alpha_3{}^2\right)}\left[\left(\frac{3}{H\alpha^5}+\frac{H}{8\alpha^3}-\frac{H^2}{12\alpha^3}\right)+\left(\frac{3}{\alpha^4}+\frac{6}{H^2\alpha^6}\right)\mathrm{e}^{\alpha\frac{H}{2}}\right]\frac{\mathrm{e}^{\alpha x}}{\alpha^2}\\
&+\frac{q\beta\left(\alpha^2\beta_3+\beta_5\right)}{k_L\left(1+\mathrm{e}^{\alpha H}\right)\left(\alpha^2-\alpha_3{}^2\right)}\left[\left(\frac{3}{H\alpha^5}+\frac{H}{8\alpha^3}-\frac{H^2}{12\alpha^3}\right)\mathrm{e}^{\alpha H}-\left(\frac{3}{\alpha^4}+\frac{6}{H^2\alpha^6}\right)\mathrm{e}^{\alpha\frac{H}{2}}\right]\frac{\mathrm{e}^{-\alpha x}}{\alpha^2}\\
&+\left(\frac{q\beta_6}{4\alpha_3{}^2H^2}-\frac{q\beta\beta_5}{4H^2\alpha^2\alpha_3{}^2k_L}\right)\frac{x^6}{30}+\left(\frac{q\beta_6}{2\alpha_3{}^2H}-\frac{q\beta\beta_5}{2H\alpha^2\alpha_3{}^2k_L}\right)\frac{x^5}{20}\\
&+\left(\frac{3q\beta_6}{\alpha_3{}^4H^2}-\frac{3q\beta\beta_5}{H^2\alpha^2\alpha_3{}^4k_L}-\frac{3\beta\beta_5q}{8\alpha^2\alpha_3{}^2k_L}-\frac{3q\beta\beta_5}{H^2\alpha^4\alpha_3{}^2k_L}+\frac{3q\beta_6}{8\alpha_3{}^2}+\frac{3q\beta_4}{H^2\alpha_3{}^2}-\frac{3q\beta\beta_3}{H^2\alpha^2\alpha_3{}^2k_L}\right)\frac{x^4}{12}\\
&+\left(\frac{3q\beta_6}{\alpha_3{}^4H}-\frac{3q\beta\beta_5}{H\alpha^2\alpha_3{}^4k_L}-\frac{q\beta\beta_5H}{8\alpha^2\alpha_3{}^2k_L}+\frac{q\beta\beta_5H^2}{12\alpha^2\alpha_3{}^2k_L}-\frac{3q\beta\beta_5}{H\alpha^4\alpha_3{}^2k_L}-\frac{q\beta_6H^2}{12\alpha_3{}^2}+\frac{q\beta_6H}{8\alpha_3{}^2}+\frac{3q\beta_4}{H\alpha_3{}^2}-\frac{3q\beta\beta_3}{H\alpha^2\alpha_3{}^2k_L}\right)\frac{x^3}{6}\\
&+\left(\begin{aligned}&\frac{6q\beta_6}{\alpha_3{}^6H^2}-\frac{6q\beta\beta_5}{H^2\alpha^2\alpha_3{}^6k_L}-\frac{6\beta\beta_5q}{8\alpha^2\alpha_3{}^4k_L}-\frac{6q\beta\beta_5}{H^2\alpha^4\alpha_3{}^4k_L}+\frac{6q\beta_6}{8\alpha_3{}^4}+\frac{6q\beta_4}{H^2\alpha_3{}^4}-\frac{6q\beta\beta_3}{H^2\alpha^2\alpha_3{}^4k_L}\\&-\frac{3\beta\beta_3q}{4\alpha^2\alpha_3{}^2k_L}-\frac{6q\beta\beta_3}{H^2\alpha^4\alpha_3{}^2k_L}+\frac{q\beta\beta_5H^3}{24\alpha^2\alpha_3{}^2k_L}-\frac{3\beta\beta_5q}{4\alpha^4\alpha_3{}^2k_L}-\frac{6q\beta\beta_5}{H^2\alpha^6\alpha_3{}^2k_L}-\frac{\beta_7}{\alpha_3{}^2}+\frac{3q\beta_4}{4\alpha_3{}^2}-\frac{q\beta_6H^3}{24\alpha_3{}^2}\end{aligned}\right)\frac{x^2}{2}
\end{aligned} \tag{4}
$$

4. Deformation Calculation and Analysis

According to the general solution and boundary conditions under different loads, the change of boundary deformation increment under different loads, stiffness of different connectors and temperature, and the change of interface deformation along the beam length under different ages are calculated. The height of the superimposed shear wall is 2700mm, and the thickness is 125mm. The steel bars of the prefabricated inner wall and the cast-in-place outer wall are 18 ⏀ 6, and the thickness of the steel protective layer is 30mm. The material properties and section parameters of shear walls are shown Table 1.

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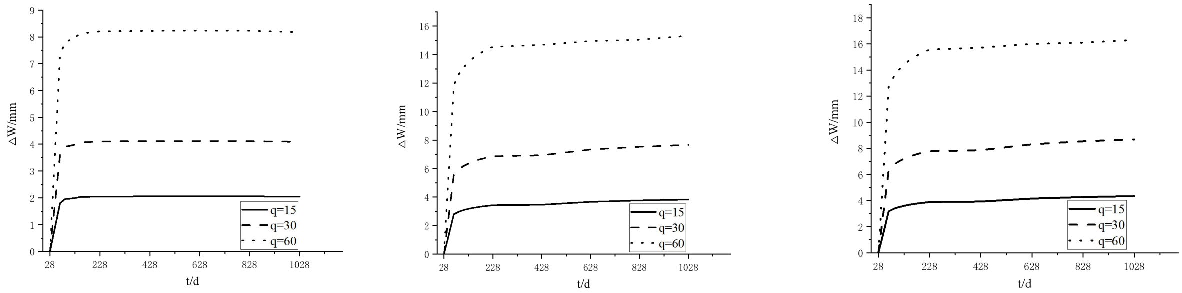
Table 1 Material properties and cross-section parameters

Material properties and section parameters	Precast interior wall	Cast-in-place exterior wall
Strength grade of concrete	C50	C30
Elastic modulus of concrete	34.5kN/mm^2	30kN/mm^2
Elastic modulus of steel	200kN/mm^2	
Thickness of protective layer of steel	30mm	
Slip stiffness	$K_L = 700\text{MPa}$	

4.1 Influence of Load on Deformation Increment

When the slip stiffness is taken as K_L and the temperature is 20°C , the variation curve of interface deformation increment with age under different loads is shown in Fig.2. During the loading period, the deformation increment of the superimposed shear wall under different loads is zero, and the deformation increment increases gradually with the increase of age.

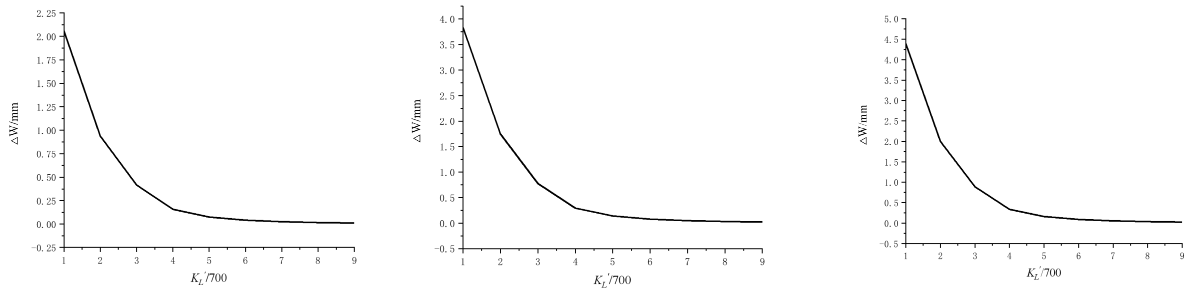


(a) Uniform load (b) Triangular load (c) Parabolic load

Fig. 2 Deformation increment-age curves under different loads

4.2 Influence of Glide Stiffness on Deformation Increment

When the age is 1028d and the temperature is 20° C , load is $q = 15\text{N/mm}$, the change curve of deformation increment and slip stiffness under different sliding stiffness and load is calculated, as shown in Fig.3. The deformation increment of superimposed shear wall decreases with the increase of glide stiffness.



(a) Uniform load (b) Triangular load (c) Parabolic load

Fig. 3 Deformation increment-slip stiffness curves

4.3 Influence of Temperature on Deformation Increment

When the age is calculated at 1028d, the slip stiffness is K_L , load is $q = 15\text{N/mm}$, deformation increment and temperature change curves under different temperatures are shown in Fig. 4. Under different load types, the deformation increment increases with the increase of temperature.

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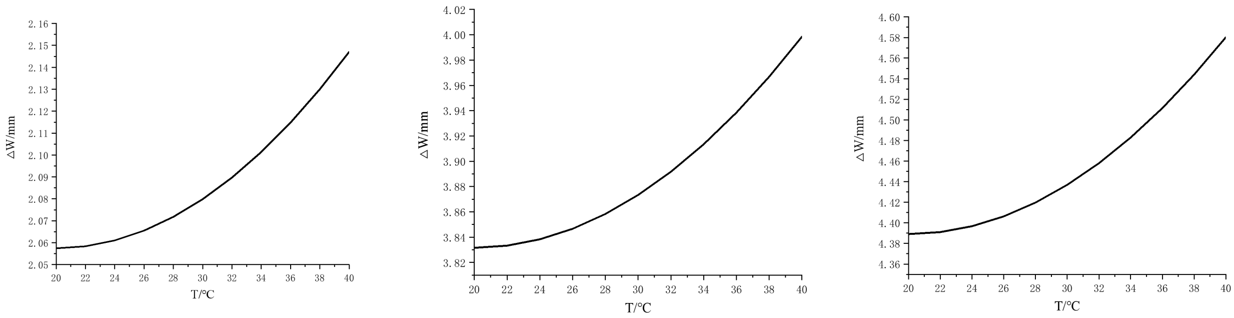

(a) Uniform load (b) Triangular load (c) Parabolic load

Fig. 4 Deformation increment-temperature curves

5. Conclusion

The deformation performance of superimposed shear wall is investigated by using the method of converted section characteristics. The influences of different loads, sliding stiffness and temperature on the deformation increment and the total deformation at different ages are analyzed. The conclusion is as follows:

(1) The increment of interface deformation of superimposed shear wall increases with the increase of load;

(2) With the increase of slip stiffness, the increment of interface deformation presents a nonlinear decrease. When the slip stiffness increases to 9 times of the initial slip stiffness, the increment of interface deformation is basically negligible;

(3) With the increase of temperature, the interface deformation increment increases with the increase of temperature, but the temperature has little influence on the interface slip increment and deformation increment of the superposition shear wall.

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